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(54) Microwave power divider

(57) A microwave power divider comprises a Wilkinson power splitter having, from its input A, a microstrip line 4 which divides at 6 into two lines 7 and 8 each $\frac{1}{4}$ wavelength long, having their outputs B_1 and C_1 connected by a resistor 9. A quadrature delay in the form of a $\frac{1}{2}$ wavelength long transmission line 10 is connected between B_1 and one output B of the divider. An incremental phase compensator in the form of a band pass filter is connected between C_1 and the other output C of the divider, and comprises a $\frac{1}{4}$ wavelength long transmission line 11 connected between C_1 and C and two $\frac{1}{4}$ wavelength long stubs 12 and 13 connected to C_1 and C and short-circuited to earth.

At the centre frequency, line 10 delays the signal by 180°, line 11 by 90° and stubs 12 and 13 have no effect, so that a 90° phase difference occurs between B and C outputs. As the frequency varies, the same phase increment occurs in the filter (by suitable selection of its characteristics) as in the line 10, to maintain the outputs in quadrature.

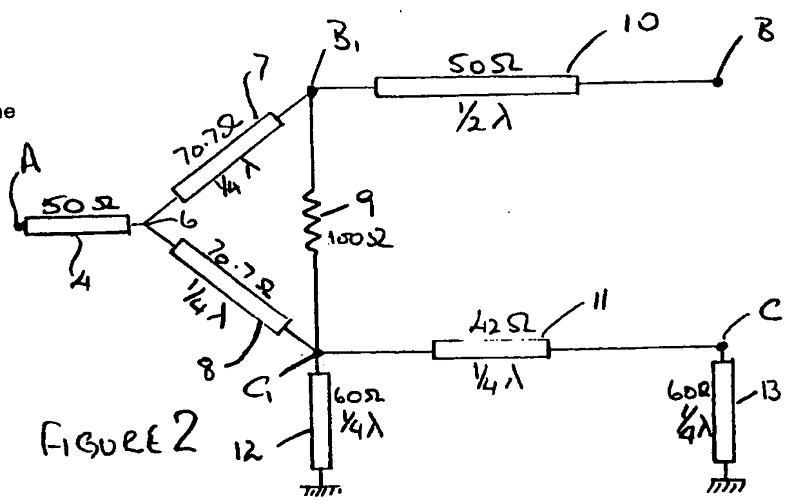

Figure 2

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

The claims were filed later than the filing date within the period prescribed by Rule 25(1) of the Patents Rules 1982.

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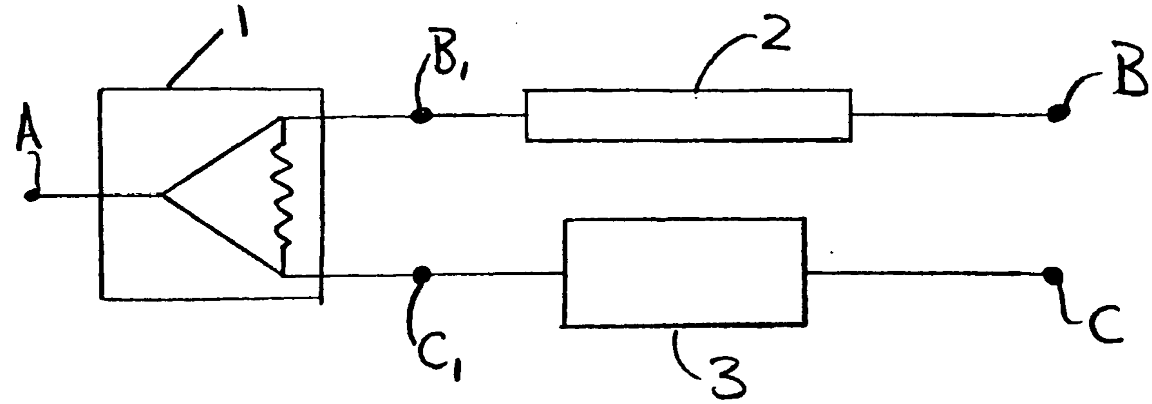

FIGURE 1

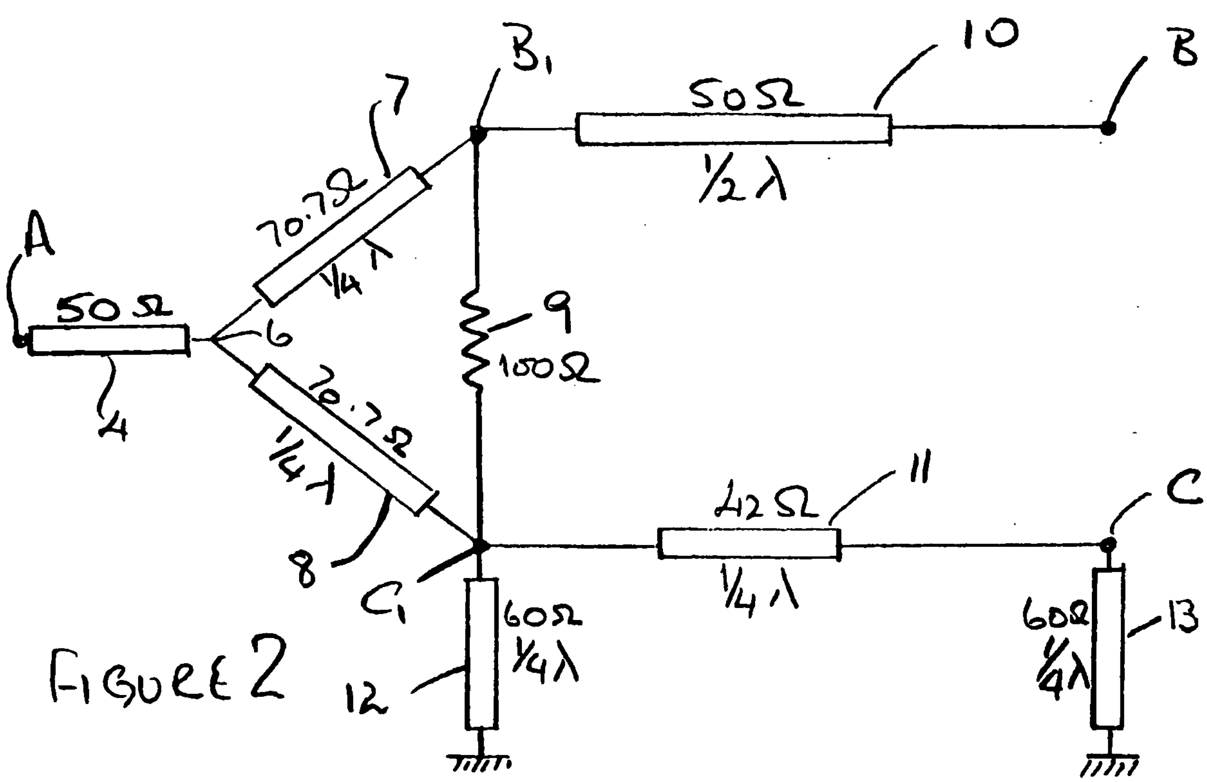

FIGURE 2

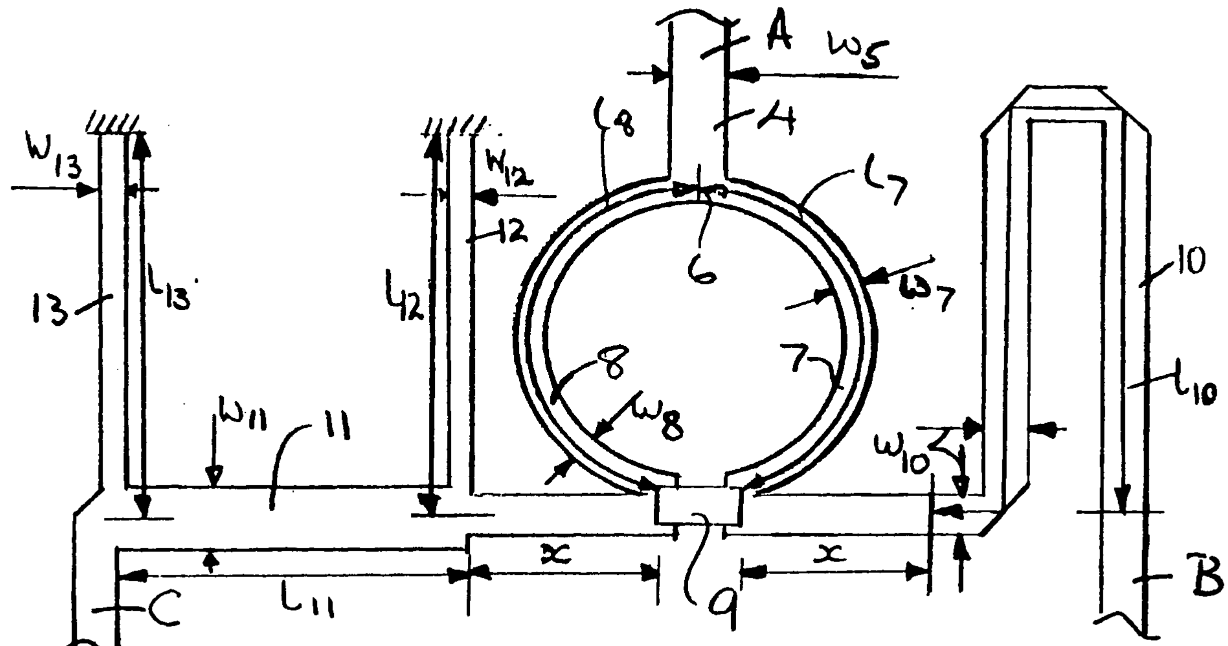

FIGURE 3

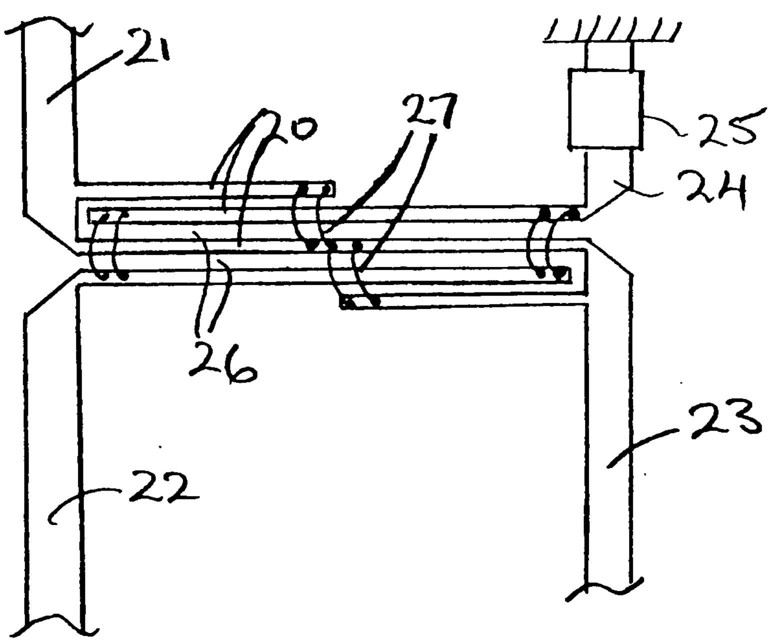

FIGURE 4

SPECIFICATION

Microwave power divider

The present invention relates to a microwave power divider.

It is convenient to be able to divided a microwave signal into two components of equal power but having a 90° phase difference between them or indeed to recombine them again. A device for achieving this is variously known as a " 3dB 90° Hybrid" or "3dB Quadrature Coupler". In this specification such a device is referred to as a "3dB Quadrature Power Divider". A typical use of such a device is in splitting a microwave signal into components which can then be individually amplified and re-combined in a similar divider to produce the original signal in amplified form.

A known wide-band power divider is the Lange coupler. I believe this to be the only wide-band power divider suitable for microwave integrated circuit applications. The Lange coupler comprises interspaced conductor strip fingers. It performs adequately at the lower microwave frequencies. Above 8 GHz the fingers become very small and are difficult to produce. In the "J" band, 10—20 GHz, the application of the Lange couple is restricted to the thin-film integrated circuits — an expensive technology. Further selected ones of the fingers must be interconnected. This is an expensive task and degrades the performance at high frequencies.

The object of the invention is to provide an improved microwave power divider.

According to the invention, there is provided a microwave power divider comprising:—

a Wilkinson power splitter, at the two outputs of which signals of substantially equal phase are present for a signal at the input of the splitter having a total power which is substantially equal split into the two output signals;

a quadrature delay connected to one output of the power splitter; and

an incremental phase compensator, in the form of a bandpass filter, connected to the other output of the power splitter, whereby the output signals of the quadrature delay and the compensator are in quadrature;

the frequency characteristics of the compensator being such that any incremental phase change in the quadrature delay due to an increment in frequency from a centre frequency is substantially matched by a corresponding incremental phase change in the compensator such that the said output signal of the delay and the compensator remain substantially in quadrature throughout a pre-determined broad-band frequency range.

It should be noted that the actual phase delay in the quadrature delay between the output of the power splitter and the output of the delay will exceed 90° by the amount corresponding to the inherent phase delay of the compensator, i.e. its phase delay at the centre frequency when the compensator produces no incremental phase change.

In the preferred embodiment the compensating bandpass filter is a direct coupled stub filter, with a characteristic impedance of Z_o. Preferably a two stub filter is employed, although one or three or possibly more may be employed.

The quadrature delay can be a transmission line of suitable length with a characteristic impedance of Z_o.

Either a compensated or a uncompensated Wilkinson splitter can be employed, having a characteristic impedance of Z_o.

The power divider of the invention is preferably manufactured in "micro-strip" form, that is in the form of conductive metallic strips of pre-determined width on an insulating substrate.

Micro-strip manufacture is mainly carried out at two different levels, namely "soft board" or "soft substrate" on the one hand and "thin film" on the other hand. Soft board circuits comprise etched copper tracks on a plastics material board. This is a relatively cheap technology. Thin film circuits comprise gold tracks on ceramic substrate. This is a relatively expensive technology.

As intimated above, the Lange coupler is restricted to a maximum practical frequency of around 8 MHz in "soft board" circuits, so that "thin film" circuits are required at higher frequencies in the "J" band. An advantage of the present invention is that it enables a "J" band wide-band 3dB quadrature power divider to be manufactured in "soft board" form. Further, it is anticipated that wide-band 3dB quadrature power dividers will be able to be manufactured at frequencues above the J band at which Lange couplers cannot practically be manufactured, again because of finger width and difficulty in connecting the necessary inter-finger wires.

To help understanding of the invention, a specific embodiment thereof will now be described by way of example and with reference to the accompanying drawings, in which:—

Figure 1 is a block diagram of a power divider in accordance with the invention; and

Figure 2 is a diagrammatic plan view of the power divider of Figure 1.

Referring first to Figure 1, the power divider comprises a Wilkinson splitter 1 having a characteristic impedance Z_o at its input A, and outputs B_1, C_1. At the splitter's output B_1, it is connected to a transmission line 2, and having the same characteristic impedance Z_o forming a quadrature delay. At the splitter's output C_1 is connected to a bandpass filter 3, forming a compensator and having the same characteristic impedance Z_o.

At the power divider's design or centre frequency, the filter 3 will delay a signal passing from C_1 to C by a certain phase. The transmission line 2 has a length such that a signal passing from B_1 to B is delayed by this certain phase plus 90°. Thus a centre frequency signal entering at A is split into two equal halves having the same phase at B_1 to C_1. Then by the time these halved signals reach the outputs of the divider at B and C, they will be 90° out of phase, i.e. in quadrature.

As the frequency of the input signal varies from the centre frequency, to two halves will remain in

phase at B_1 and C_1. However the phase delay in the line 2 will vary linearly with the frequency. As the frequency increases by an amount Δf, the phase delay will also increase by an increment $\Delta\psi$. If the filter 3 were a transmission line of length equivalent to 90° less than that of the line 2, the equivalent increment in phase would be less than $\Delta\psi$ leading to the signals being out of quadrature at B and C. To compensate for this, the group delay characteristics of the filter 3 are chosen such that substantially the same phase increment $\Delta\psi$ occurs in itself as occurs in the line 2 for the frequency increment Δf. $\Delta\psi$ in the line 2 is linear with Δf. Accordingly, although the invention is not intended to be so restricted, the characteristics of the filter 3 are chosen to give an approximately linear compensation.

Turning now to Figure 2, a view of the power divider in 50 ohm micro-strip form is shown. A 50 ohm line 4 from the input A divides at 4 into two 70.7 ohm lines 7 and 8, each ¼ wave long. The nodes B_1 and C_1, at the ends of these lines, are interconnected by a 100 ohm resistor 9, to form an uncompensated Wilkinson power splitter. The quadrature delay is provided by a ½ wave long 50 ohm transmission line 10, connecting node B_1 to node B, that is one output of the network. Node C_1 is connected to node C via a ¼ wave long 42 ohm line 11. The other output of the network is node C. Two short-circuited to ground 60 ohm ¼ wave long stubs 12 and 13 are connected to node C_1 and C, to form, together with line 11, a bandpass filter.

At the centre frequency, line 10 delays the signal by 180°C, line 11 delays the signal by 90° and stubs 12 and 13 have no effect, leading to 90° and stubs 12 and 13 have no effect, leading to 90° phase difference at the outputs B, C. The bandpass filter, having the 42 ohm line and the 60 ohm stubs, displays a 2 pole chebyshev 0.1 dB rippled type of response. Referring to filter tables, such a filter has approximately 1.6 second pass band normalized group delay. As a 90° delay expressed as normalized group delay is 1.57 sec., it is apparent that the phase change in the delay line is compensated in the pass-band of the bandpass filter, thus the output phase differential of 90° is maintained.

The power divider of Figure 2 has the following characteristics:

Characteristic impedance:	50 ohm
Relative Frequency Range:	0.66—1.34
Amplitude Flatness:	± 0.05dB
Phase between B & C:	90° ± 5
Return loss at port C:	better than 16 dB

It should be noted, that by varying the parameters of lines 11, 12 and 13, different performance characteristics can be obtained. For instance with higher line impedances a Butterworth type of filter response can be achieved. This will improve the return loss and the amplitude/phase ripple at the expense of a reduction in band width.

Turning now to Figures 3 and 4, the preferred physical track layout of a power divider of th invention can be seen in Figure 3 and an equivalent layout for a Lange coupler can be seen in Figure 4.

In Figure 3, the reference numerals and letters have the same signifance as for Figure 2. For:—

Frequency Range of	7 to 14 Ghz, and
A Substrate Dielectric constant (e_r) of	10.2,

the tracks have the following lengths:—

l_7	2.8 mm
l_8	2.8 mm
l_{10}	5.4 mm
l_{11}	2.7 mm
l_{12}	2.75 mm
l_{13}	2.75 mm

The x dimensions are of equal length.

The width of the tracks is dependent upon the dielectric, i.e. board, thickness to an earth backing plate. For a typical substrate thickness of 0.635 mm, which is suitable for a soft substrate or a thin film circuit, the tracks have the following widths:—

w_5	0.61 mm
w_7	0.25 mm
w_8	0.25 mm
w_{10}	0.61 mm
w_{11}	0.80 mm
w_{12}	0.40 mm
w_{13}	0.40 mm

These widths are achievable with conventional soft board techniques.

By contrast, the Lange coupler of Figure 4 has small width fingers 20 to which wires 27 must be connected. For the same frequency range, dielectric constant and thickness, the Lange coupler has an input track 21 and two output tracks 22, 23 all of equal width of 0.61 mm as 50 ohm lines. One of the terminals 24 of the Lange coupler is connected to earth via a 50 ohm resistor 25.

These lines have their interdigitated fingers 20 spac d by gaps 26. These have the following widths:—

Fingers 20	0.06 mm
Gaps 26	0.05 mm

This it can be seen that in comparison with the power divider of the invention, the Lange fingers are approximately a quarter of the width of the narrowest lines of the invention. The gaps 26 also are equally narrow. Besides the difficulty in forming these fingers 20 the wires 27 must be attached to them.

When higher frequency power dividers are to be made, thinner dielectrics are advisable. Track widths are reduced linearly with dielectric thickness. Thus it will be appreciated that when the limit with increasing frequency of the feasibility of manufacturing Lange couplers in any technique is reached, the narrowest tracks of an equivalent power divider of the invention are still four times as wide and no wire bonding is required. Accordingly power dividers of the invention can be constructed to operate at higher frequencies.

CLAIMS

1. A microwave power divider comprising:—

a Wilkinson power splitter, at the two outputs of which signals of substantially equal phase are present for a signal at the input of the splitter having a total power which is substantially equally split into the two output signals;

a quadrature delay connected to one output of the power splitter; and

an incremental phase compensator in the form of a band pass filter connected to the other output of the power splitter, whereby the output signals of the quadrature delay and of the compensator are in quadrature.

2. A divider according to claim 1, in which the frequency characteristics of the compensator are such that any incremental phase change in the quadrature delay due to an increment in frequency from a centre frequency is substantially matched by a corresponding incremental phase change in the compensator, so that the output signals of the quadrature delay and of the compensator remain substantially in quadrature over a pre-determined broad-band frequency range.

3. A divider according to claim 1 or 2, in which the actual phase delay in the quadrature delay between the one power splitter output and the delay output exceeds 90° by the amount corresponding to the inherent phase delay of the compensator at a centre frequency when the compensator produces no incremental phase change.

4. A divider according to claim 1, 2 or 3, in which the compensating band pass filter is a direct coupled stub filter, with a characteristic impedance of Z_o.

5. A divider according to claim 4, in which the filter is a two stub filter.

6. A divider according to any preceding claim, in which the quadrature delay is a transmission line of selected length with a characteristic impedance of Z_o.

7. A divider according to any preceding claim, in which the Wilkinson splitter is compensated, having a characteristic impedance of Z_o.

8. A divider according to any of claims 1 to 6, in which the Wilkinson splitter is uncompensated, having a characteristic impedance of Z_o.

9. A divider according to any preceding claim, manufactured in the form of conductive metallic strips of predetermined width on an insulating substrate.

10. A divider according to claim 9, in which the components comprise etched copper tracks on a plastics material board.

11. A microwave power divider substantially as hereinbefore particularly described with reference to Figures 1 and 2 of the accompanying drawings.

12. A microwave power divider substantially as hereinbefore particularly described with reference to Figures 1 to 3 of the accompanying drawings.

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